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Making L2 learners' reasoning skills visible: The potential of Computer Supported Collaborative Learning Environments

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ABSTRACT

This paper explores the use of Computer Supported Collaborative Learning Environments (CSCLE) as multimodal spaces for promoting critical thinking for English as Second Language Learning (L2) education from multiple perspectives (Technology, Thinking Skills and Interaction). The exploration focuses on the use of a multitouch tabletop, and an accompanying application called Digital Mysteries, as affordances in CSCLE's for making reasoning skill-based thinking visible for L2 learning in Higher Education.

Despite the worldwide promotion of teaching thinking in L2 education, it is not always easy for teachers to identify the types of thinking skills being targeted in L2 pedagogical tasks. To the authors' knowledge, little empirical interactional evidence is available to demonstrate critical thinking in L2 learner talk during group work. This paper examines interactions among three groups of Chinese English Language learners at a higher education institution in a CSCLE. Video data were collected of students' thinking-in-action whilst engaging in multimodal interactions in the environment. Results show that new technologies can provide innovative and empirically driven ways in which L2 learners' thinking is externalised and how critical reasoning can be tracked, promoted, evaluated and self-regulated. The findings suggest that collaborations in a CSCLE can support the completion of tasks embedding high levels of cognitive complexity by L2 learners with effective use of limited cognitive resources. This leads to a number of recommendations about integrating the teaching of critical thinking skills into the L2 classroom using CSCLE technologies.

1. Introduction

Critical thinking has been recognised as one of the key skills for citizens in the 21st century. However, how to integrate teaching critical thinking into second language (L2) classrooms can be more challenging to language practitioners than those of other subjects. Empirical studies of Chinese college students have found that students of non-English majors perform better than those of English majors in critical thinking tests. This observed 'absence of critical thinking' (Huang, 1998) was also reported of students from other non-English speaking countries, and an overemphasis on language skills and on

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memorisation in the teaching English as a foreign language (He, 1999; Sanavi & Tarighat, 2014) was claimed to be one of main causes.

With English being both the subject of and means for learning, and means for thinking and communication, adequate language skills of students have been a long standing concern or even scepticism for teachers to introduce higher order thinking tasks to second language lessons (Wen & Zhou, 2006). Equally, lack of language skills and vocabulary tends to be cited by students as one main reason for preventing them taking active part in discussions (Lee, 2004), causing a cognitive block (Peng, 2014), or blank or frozen brain (Chen, 2010) even for students with intermediate or higher level of language proficiency (Kim, 2006). Empirical studies on students' willingness to communicate found that skills in reasoning and critical thinking could influence students' ability to initiate or carry on communication in a L2 (Peng, 2014). This led us to question whether reported problems in oral communication are due to language deficiency or cognitive overload involved in the processes of conceptualisation and representation of ideas.

In this paper, thus, we will examine the cognitive complexity of critical thinking tasks in L2 through the use of digital technology. The analysis allows us to explore the extent to which affordances of Computer Supported Collaborative Learning environments (CSCLEs) can facilitate L2 students' collaborative management of competing cognitive factors to develop their reasoning skills orally, and via thinking in action. Analysed episodes of interaction in the solving of digital mysteries are used to illustrate the presence of critical thinking and reasoning through L2 learner talk during group work. We finish with pedagogical implications and suggestions for teaching critical thinking with new technologies.

2. Cognitive complexity of reasoning in L2 & CSCLEs

2.1. Critical thinking and reasoning

Abilities to analyse, evaluate, and infer are recognised as core skills in critical thinking (Ennis, 2011; Halpern, 2003; Moseley et al., 2005; Paul and Elder, 2012). Paul and Elder (2012) believe that critical thinking involves three interwoven phases – analysing thinking, evaluating thinking, and improving thinking. They stress that the quality of thinking is dependent on abilities to reason and reason well. This implies that learning to reason is fundamental to develop these core skills. Jewell's taxonomy (Table 1) provides a simple framework focusing specifically on reasoning involved in critical thinking (cf. Ennis, 2011; Halpern 2003; Paul and Elder, 2012). Jewell defines reasoning as "purposeful thinking. It orders information in order to produce a result" (1996, p. 5). His framework identifies main functions of reasoning and strategies to 'help students achieve the purpose of reasoning . . . and develop the dispositions or habits of mind which in turn to facilitate the ongoing process of enquiry (Moseley et al., 2005, p. 172). The clear descriptions and explanations of the purpose, strategies and dispositions of reasoning offer a model to interpret and analyse verbal reasoning in L2. We believe that this is one of the most undervalued and poorly developed set of skills for L2 learners specifically. Most relevant to this study are: the extent to which technology fosters explicit construction of arguments (B3); considerations of the supporting the evidence (B4) and deepening students' enquiry and understanding through community of inquiry (B1). Enquiry and understanding are presented (by Jewell) as the superordinate goals of reasoning (Moseley et al., 2005, p. 172), and are central to the technological application used in this study.

Table 1
Jewell's reasoning taxonomy (Jewell, 1996).

Section A The Objectives of Reasoning

1. To plan
2. To problem solve
3. To decide
4. To recommend
5. To communicate

Section B Reasoning Strategies

1. The Community of Inquiry
2. Model construction
3. Argument construction
4. Considering the Evidence
5. Moral reasoning

Section C Reasoning Dispositions

1. Question own position
2. Seek and offer justification for views
3. Adopt alternative models
4. Empathise with the beliefs, values and thinking processes of other people

2.2. Reasoning and complexity in the L2

Thinking critically in the L2 entails a complex cognitive process, which might not always be made explicit to teachers and learners in Higher Education courses. Drawing on cognitive hypothesis theories, Robinson (2005) suggests that cognitive complexity of pedagogical tasks can be examined by cognitive, interactional and learner factors (Table 2). According to Robinson, if tasks require dual or multiple simultaneous steps to complete, referring to events that happened in the past or not at present, or demand reasoning, they are more complex cognitively than those requiring single step to complete, referring to events happening here and now, or with no demand for reasoning. In his view, unavailability of planning time for the tasks, number of tasks students need to be performed simultaneously, and lack of prior knowledge of the tasks can also increase the task complexity.

Table 2
A triad of task complexity, task conditions and task difficult factors (Robinson, 2005, p. 5).

Task complexity (cognitive factors)	Task conditions (interactional factors)	Task difficulty (learner factors)
a) Resource-directing	a) Participants variables	a) Affective variables
e.g. +/− few elements	e.g. open/closed	e.g. motivation
+/− Here-and-Now	one-way/two-way	anxiety
+/− no reasoning demands	convergent/divergent	confidence
b) Resource-dispersing	b) Participants variables	b) Ability variables
e.g. +/− planning	e.g. same/different gender	e.g. working memory
+/− single task	familiar/unfamiliar	intelligence
+/− prior knowledge	power/solidarity	aptitude

Based on Robinson's criteria, able to actively participate in discussions, which most L2 learners reported problems with, can be interpreted as a cognitively complex task because of multiple processing inherent in this performance (Baralt, 2015). Before students can participate in discussions, they need to be able to judge credibility of what is being presented and respond accordingly. This requires them not only to understand the points presented by other speakers, but also listen critically so as to analyse the points or arguments being presented (Bloom & Krathwohl, 1956; Paul & Elder, 2012). Due to the transitory and temporary nature of spoken information, they also have to hold the information in their memory in order to process it for analysis and evaluation. These multiple and simultaneous tasks of comprehension, memorisation, recall, analysis and evaluation, and construction of well-reasoned responses will inevitably compete for attentional, memory and information processing space in their working memory, and cognitive resources. Planning their response on the spot would add to the existing complexity of discussion tasks. Thus, a seemingly simple discussion task can be very high in terms of cognitive complexity. Therefore, 'don't know what to say' might not be solely due to linguistic deficiency, but to the cognitive complexity of the tasks as well as effective and efficient management of the use of limited cognitive resources. Increasingly technologies have been used to mediate learning of second language. Research on computer mediated communication (CMC) suggests that CMC can alleviate constraints on working memory when performing cognitively complex language learning tasks involving face to face interactions (Baralt, 2015).

2.3. Computer supported collaborative learning environments

The increase in access to new technologies in education offers new opportunities for L2 learners. There is now an abundance of internet-based applications and materials for individual L2 learners to develop their linguistic skills. Although not as abundant, there are a growing number of digital technologies which enable and facilitate L2 learning through collaborative activities and the facilitation of knowledge and expertise sharing. Referred to as Computer Supported Collaborative Learning (CSCL) (Lee, 2004; Lund, 2008), this area of research and development is seen to hold many learning benefits such as increased satisfaction, improvement in academic achievement, and the development of higher order thinking skills (Resta & Laferriere, 2007). Most research in the field of CSCL has focused on collaboration through remote and synchronous or asynchronous communication (Hilliges et al., 2007) with face to face communication receiving less attention. For L2 learners who desire and need to learn a language for study or work in another language where complex face to face communication is essential, *face to face* Computer Supported Collaborative Learning Environments (CSCLE, henceforth) arguably hold better opportunities for L2 learners.

The use of a digital tabletop in this environment provides a focus for our advanced investigation into the affordances of CSCLEs for promoting thinking skills for second language learners. One of the distinguishing features of a digital tabletop is its large-horizontal interactive surface which integrates simultaneous multi-user support (Higgins, Mercier, Burd, & Joyce-Gibbons, 2012; Kharrufa & Olivier, 2010). Digital tabletop applications can integrate multiple affordances. They enable direct manipulation of learning content or information (either by pen or touch) and this, combined with large horizontal design, enables learners' awareness of actions and participation levels.

The notion of the tabletop being part of an environment takes the focus away from a technology-driven perspective to one which considers learning processes as a multimodal learning experience. This perspective treats learning as a holistic

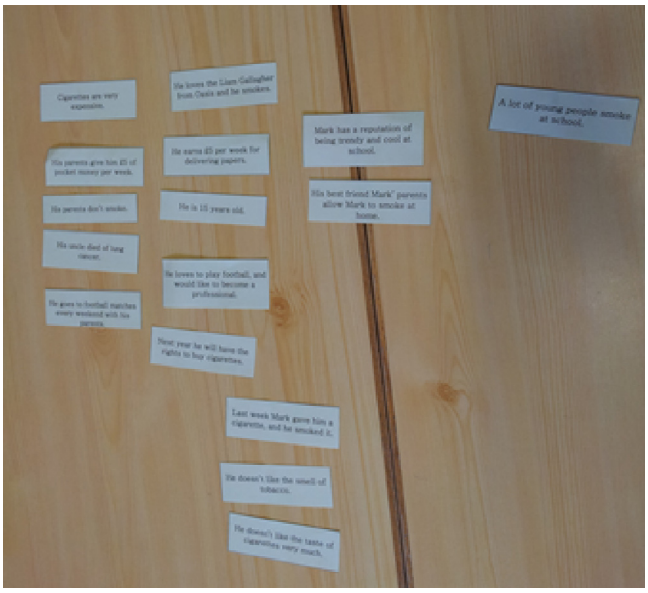


Fig. 1. A paper mystery: Is Paul going to start smoking? (Lin and MacKay, 2004).

experience whereby interactions are not only between learners and the tabletop but also between learners themselves. The environments is a co-located multimodal learning space where learning behaviours and processes are inextricably intertwined with technological tools. As such, we conceptualise learning as situated within Sociocultural theories of second language learning (Lantolf, 2003; Lantolf & Thorne, 2006). Recent work in the design and implementation of digital tabletop technology has shown the unique affordances that these new technologies can have on promoting peer collaboration and learning via structured tasks, externalisation tools, feedback and reflection prompts, face-to-face collaboration, multi-synchronous interaction, and increased participation awareness (Dillenbourg & Traum, 2006; Kharrufa, Leat & Olivier, 2010; Martinez-Maldonado, Collins, Kay, & Yacef, 2011). There is less known about the affordances of these environments for promoting critical thinking of second language learners more specifically. Emerging empirical studies on technology-assisted gains on critical thinking skills for L2 learners tend to focus more on the outcomes but less on the process, and the latter would benefit both teachers and learners. Heslop et al. (2015) offer a holistic lens to examine the nature and quality of collaborative interactions over time across 8 groups of students using multitouch tabletops. This is based on an analysis of 'decision points' bringing students together to collaborate. Hence, the current study also extends the scope of the affordances of digital tabletop technology and applications for promoting critical thinking for L2 learners more specifically as a tool for making thinking explicit.

In the following section, we present a detailed introduction to the Digital Mysteries application used as part of our study into the affordances of CSCLEs in supporting L2 learners to manage cognitive complexity in developing their reasoning skills in an oral task.

3. Descriptions of Digital Mysteries task

Digital Mysteries (DM henceforth) (Kharrufa, Leat et al., 2010) is a computer-based learning application designed to promote collaboration and higher level thinking skills for multiple users. It is based on a paper-based mysteries learning approach which was created for the development and assessment of students' higher level thinking skills (Leat & Nichols, 2000). In the paper-based version (Fig. 1), students are given a number of slips of paper containing facts, background information, abstract ideas, and some red herrings. Central to the learning benefit of a mystery in this context is that students are asked to use this information to answer an open question that does not have *one right* answer and through the manipulation of slips to solve the mystery, the cognitive processes of the students are made evident.

During the process of solving a mystery, students engage in discussions to express their ideas which can lead to levels of thinking that they wouldn't normally achieve alone. This makes it possible for an observer to assess the level of thinking of the students through careful observation of the students while engaged in the activity (Leat & Nichols, 2000). These qualities led both the SynergyNet team (e.g. Higgins et al., 2012; Mercier & Higgins, 2014), and Kharrufa, Olivier, and Leat (2010) (in their work on Digital Mysteries) to build different digital interpretations of mysteries to combine the affordances of digital technology and those of the mystery task itself.

The main design features for DM are: externalization of thinking (or making thinking visible), encouraging collaboration, and promoting feedback, reflection and metacognition (Kharrufa, Olivier et al., 2010). These goals are achieved by introducing externalization tools, switching between parallel input (all students attend to the same piece of information or aspect in the

Fig. 2. Externalization tools: named group (dark blue area), normal and arrow sticky tapes, and note tools. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

interaction with the application), single input (individual students can attend to a particular aspect), enforced collaboration (consensus points), structuring the task into stages, and providing a dedicated reflection stage.

3.1. DM design features

The following section details these design features and how they link to learning benefits.

3.1.1. Externalization of thinking

Externalisation of thinking is to make thinking visible to oneself and to others. One limitation of paper mysteries as regards externalisation of thinking is that when students put slips in piles, or next to each other, they do not necessarily have to explain their actions to each other, and it is not possible for an observer to make sense of the layout of the slips (Fig. 1). In DM, *Named group tool* and *Relation or Sticky tape tool* were specifically designed to address this (Fig. 2). *Named group tool* allows the creation of explicit groups and asks students to enter a name for the new group. All students have to agree on the name, and the process of creating and naming groups is likely to trigger useful moments of discussion. *Relation or Sticky tape tool* makes it possible for students to link two or more slips together using either a normal shape sticky tape (to indicate normal relation) or arrow shaped sticky tape (to indicate causal or temporal relation). Using the sticky tapes can trigger useful discussions requiring students to explain why they think the slips are related and discuss the type of relation (the type of sticky tape to use).

The use of these tools not only triggers useful task-related discussions, but also makes the students' thinking more visible thus more accessible to an external observer such as another student or a teacher-facilitator. This provides opportunities for providing richer feedback.

3.1.2. Encouraging collaboration

DM uses three specially designed features to promote collaboration. In the case of this study, the use of a pen-based tabletop version of the application (rather than a multi-touch one) makes it possible to identify (or distinguish between) users as each student uses a different pen to directly interact (select and move objects around on the tabletop surface) which is recorded by the application and presented back to students in real-time in the form of a pie chart of their individual contributions shown on the tabletop (see Fig. 3). This feature also complements and benefits from the learning benefits of externalisation of thinking given its associated presentation function.

Secondly, collaboration is also enhanced through collaborative coupling, the way in which tabletop supports a group of students to instantaneously move between individual and group work in the task which is also visible to all participants. Collaborative coupling allows parallel input (e.g. all students can interact with the slips at the same time) as well as single input (e.g. providing single soft keyboard for text entry).

A third design feature is the use of enforced collaboration interaction tools which are initiated at key decision points such as entering a thematic group name in the grouping stage (Fig. 4) or at movements between stages (see 3.2). Enforced collaboration can be viewed as consensus points requiring all students to agree through direct interaction using the pens to confirm their participation in the group level decisions.

3.2. Structuring the task

When higher achieving students solve a paper mystery, they typically go through three stages: reading the slips, putting the slips in groups, then building a branched (or webbed) sequence that reflects their reasoning. Accordingly, DM guides the students through a similar structure but with a number of enhanced design features.

- *Reading Stage*: DM enables students to resize and move the slips. Slips initially appear in a small unreadable size and students cannot proceed to the next stage unless all slips have been read (made possible by directly manipulating the slips with the pens to make them larger).
- *Grouping Stage*: This stage provides the named group tool, the normal sticky tape, and the note tool. Students cannot proceed unless all slips are put in at least three groups. The aim is to encourage students to organize and categorize information (i.e. look at the problem from the perspective of information categories).
- *Sequencing stage*: This stage introduces the arrow shaped sticky tape in addition to the previous tool. Students are expected to take the slips out of their groups and start building a layout using normal and arrow sticky tapes that reflects their reasoning about the problem and supports their answer. The aim is to encourage students to look at the information from a different perspective focusing on causal and temporal relations.

In addition to peer feedback during the process, structuring the application into stages, allows for the provision of feedback to students at incremental points during the task. These can occur in between stages through student-initiated discussion and via the DM application via inter-stage reflective prompts (Kharrufa, Olivier et al., 2010). After completing all the stages, the students are asked to type their written answer into the application and after a consensus point, proceed to the reflection stage.

Although the Digital Mysteries application was not specifically designed for L2 learners, when used within the context of a CSCL, it holds a number of features which we identified as showing its relevance for use with L2 learners more specifically in this study:

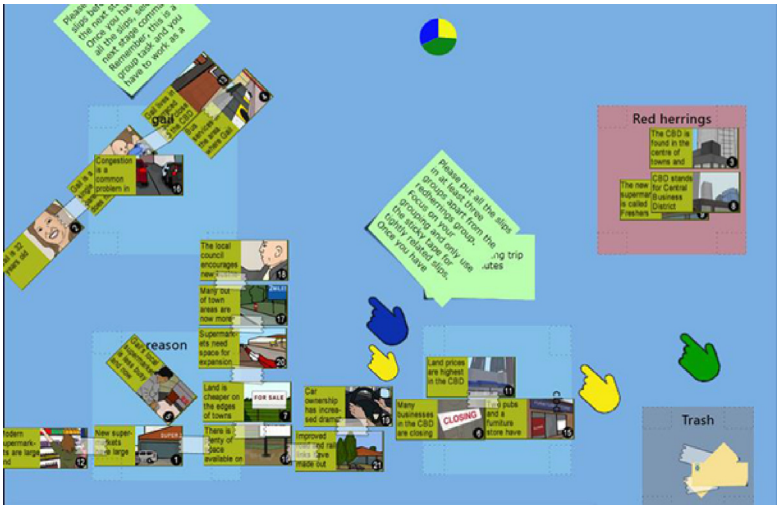


Fig. 3. Digital Mysteries interface with pie chart of contributions.

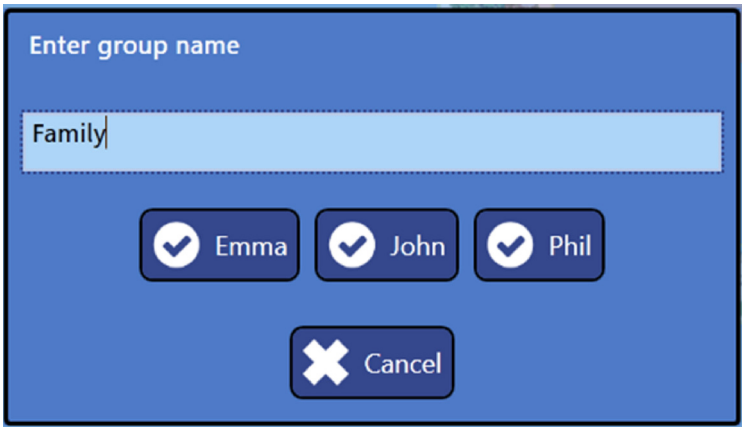


Fig. 4. Consensus points when naming and creating groups.

1) it allows students' thinking to become externalised on the table, so it can be viewed by students themselves and others, which leads to manipulate, modify and mediate each other's thinking;
2) with the information accessible on the table and presented in front of the students, it allows students to talk about events that happened in the past as if they are happing 'Here-and-Now' (Robinson, 2005). More specifically relevant here is that students use their cognitive resources more effectively to prioritise cognitive resources to think rather than recalling and memorising information;
3) with the information and map of their thinking on the table ('brains on the table') (Leat & Nichols, 2000), it allows students to think simultaneously as well as interactively.

4. Research design

This section introduces the study design and research methods taken to address the overarching research question of the extent to which CSCLEs can support L2 learners in their management of complexity whilst developing reasoning skills in oral tasks.

To answer this main question, three sub-questions are considered:

1) What kinds of reasoning skills are emphasised and promoted in the CSCLE?
2) How does the CSCLE support 'thinking in action' in terms of the organisation of reasoning skills?
3) Based on answers to the above, what affordances in the CSCLE, which includes a tabletop application, can be identified as specifically supporting the management of complexity for L2 learners?

4.1. Participants

Nine postgraduates following a Masters programme in Applied Linguistics and TESOL (2013–2014) participated in this study. They were aged between 21 and 29 and had achieved an IELTs score of 6.5–7. Prior to participating in this study, they were introduced to the DM tabletop application as part of a module on Thinking Skills in Second Language Learning. Whilst there are recognised limitations in sample size as the study involved only nine students, our research questions focused on a holistic approach to the nature and quality of multimodal interaction as it is constructed in the moment-to-moment dynamics of the environment. In the case that we had sought to 'quantify' instantiations of pre-specified behaviours, we believe a larger sample size would have been more appropriate.

The nine students were randomly divided into three groups and worked on the same DM task once, but separately. The DM user guide was sent to the participants prior to the data collection, and detailed instructions on how to use tabletop were given before participants started the DM task. The names of the students in this paper are pseudonyms. Full ethical clearance was obtained and written informed consent was provided by the participants for this publication and any accompanying images.

4.2. The DM task

The topic of the DM task used in this study was 'Shopping and Land Use Change', which describes a scenario that a supermarket in the city centre has to move to the edge of the city because of the shortage of available land. Twenty-one individual digital slips were available on the tabletop and participants were asked to answer 'Why does Gail's weekly shopping trip take 40 min longer?' (Fig. 5). The slips include a couple of red herrings and a few key factors. Students were asked to come up with reasons themselves. They completed the task mainly guided by the instructions on the tabletop or by using their own initiative. After completing the task, they were asked to give a verbal presentation of their answers to the question.

4.3. Data collection methods

Observation methods provided the main source of data for the study which allowed us to view the processes involved in the students' completion of the DM task through multiple lenses. For each of the DM sessions (n = 3) two video cameras captured the verbal and non-verbal communication in the environment from two different physical angles. Audio-recordings served as a detailed record of verbal communication which enhanced the production of multimodal transcriptions. As well as the audio and video streams, the digital tabletop recorded interaction logs of all activities taking place on the table consisting of individual and group contributions at each stage. When triangulated with interaction log data, the observation data provided us with a detailed view of the role and quality of the mediation of reasoning skills in the CSCLE.

4.4. Data analysis approach

In keeping with the holistic approach we took to conceptualising learning in this environment, the approach to data analysis was carried out by viewing the sessions through three different lenses: thinking-in-action, use of reasoning skills and finally, in terms of the specific design features of the tabletop application. The first two analytical lenses were designed

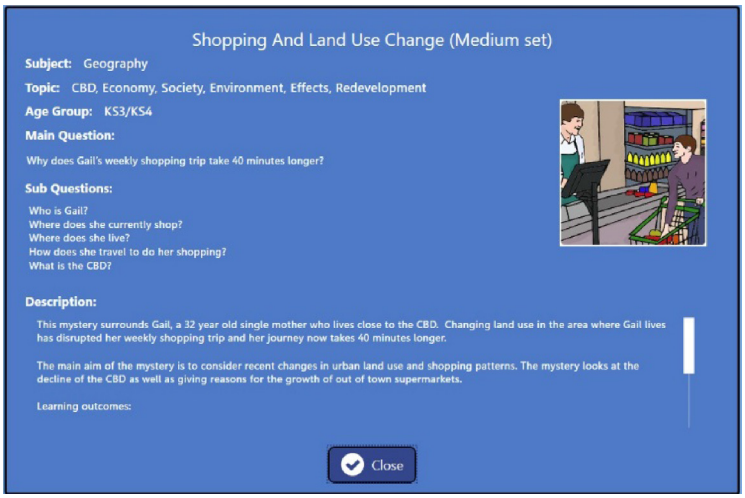


Fig. 5. Task description for 'Why does Gail's weekly shopping trip take 40 min longer?.

to explore the quality of L2 learners' management of complexity in the application of reasoning skills in the environment (constructed through the interactions of the students with the tabletop, the DM application and each other). The third aimed to ascertain to what extent the design features more specifically influenced the learning processes.

4.4.1. Thinking-in-action

The lens of thinking-in-action was used to analyse the visibility of reasoning skills as evidenced in verbal and non-verbal communication in the overall structure and organisation of the task. In addition, thinking-in-action was used to complement the more detailed analysis of specific episodes which exemplified specific functions of reasoning skills when using the second lens. Here, 'thinking in action' is concerned with the multiple modes through which the interaction is constructed. It makes the assumption that meaning-making is embedded in the physical and social interaction in, around and with the technology and as such, such can be viewed as an approach to studying 'embodied cognition' (Jewitt, 2009). This approach can be synthesized with established work in the L2 learning sciences growing out of sociocultural perspectives on L2 learning such as that of Van Lier (2004).

4.4.2. Presence of reasoning skills

Jewell's (1996) reasoning framework was adapted to interpret presence of students' reasoning skills in three transcribed sessions of DM. Situated in community of Inquiry (Lipman, 2003), Jewell's framework exemplifies behaviours including objectives, strategies and dispositions involved in reasoning processes within groups. It provides useful guidance to identify relevant episodes with evidence of reasoning skills and carry out detailed analyse of types of reasoning skills and abilities to evaluate and infer. The emphasis in this part was on an investigation of the function between the students while solving the mystery as opposed to form.

Once identified, the development of reasoning skills were further coded and analysed according to multimodal features representing 'thinking-in-action' in the interaction revealed through video data and interaction logs as described in 4.3.

5. Results and discussion

This section begins with the overall structure and organisation of the sessions to provide a quantitative overview of the visibility of 'thinking in action' in the development of reasoning skills during the task.

5.1. Thinking-in-action

In terms of the overall structure and organisation of the sessions, providing an indication of overall visibility of reasoning skills, there are a number of measures used to evidence 'thinking-in-action'. In the first instance, Fig. 6 shows the total number of participant turns produced by the participants in each group. A participant turn is defined and used in the case of this analysis as an interactional event which is collaboratively constructed by participants out of one or more Turn Constructional Units (TCUs). It is important to note here that the way turns are taken and constructed in the session varied according to how their producer designed their 'thinking in action' in multiple modes. That is, it could have been a verbalised turn of talk or other social action which is carried out non-verbally or with both non-verbal and verbal actions being carried out simultaneously and thus embodied interaction. The nature and quality of the turns are explored in more detail in Section 5.2.

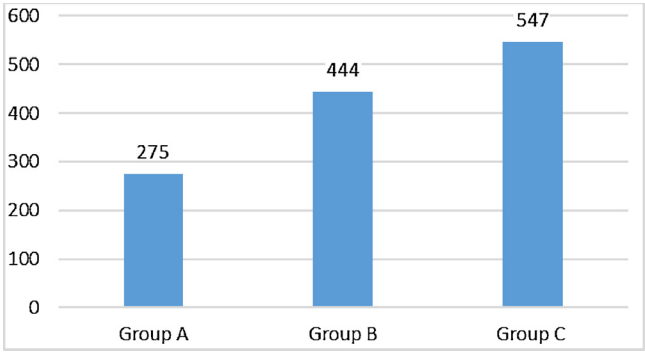


Fig. 6. Total number of participant turns per group.

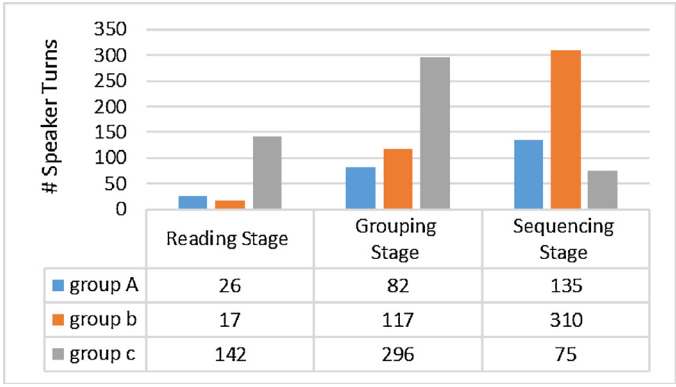


Fig. 7. Distribution of participant turns per group and at each stage.

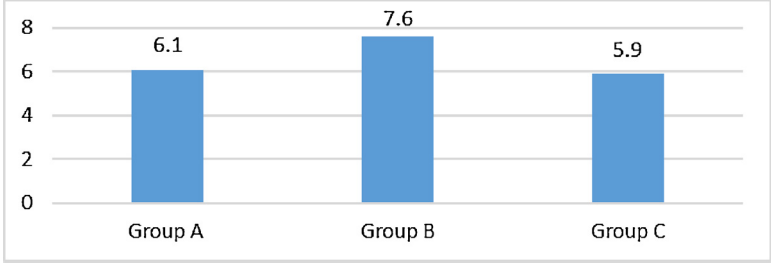


Fig. 8. Mean length of participant turns per group.

Fig. 7 shows the overall distribution of interactions measured in terms of number of participant turns at the different stages of reading, grouping and sequencing during the DM task. Fig. 8 shows the mean length of participant turns, measured in words. Fig. 9 displays the total time taken to complete the task from the initiation of the reading stage to the group consensus that the answer had been reached at the end of the sequencing stage.

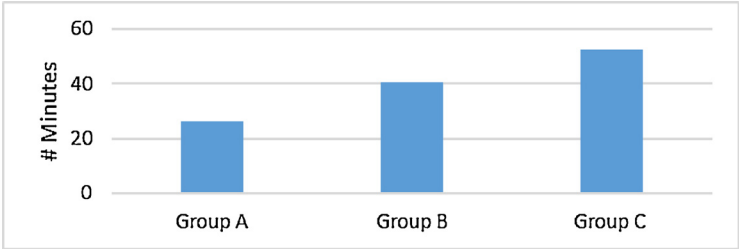


Fig. 9. Task completion time per session per group.

The completion of each stage for individual groups was evidenced via interaction logs when students used the application feature to move between stages (consensus points). Observation data also showed that students' discussions were not always confined by the nature of the stage. Likewise, students tended to combine reading and grouping actions rather than rigidly finishing reading before beginning grouping, and sequencing. Having said that, the differences indicated by the number of turns give a good indication of how long each group engaged in discussions at individual stages.

5.2. Use of reasoning skills & thinking in action

In this section, the nature and quality of reasoning skills are the focus, and complemented by an analysis of 'thinking in action' in terms of multimodal behaviour. Together, function and form of reasoning skills highlight how reasoning skills were made visible to and by the students as they managed the complexity of the task in the CSCLE whilst using the L2.

5.2.1. Comprehension

At the Reading stage of the DM, students were instructed to enlarge and read each of the slips provided. In this context, comprehension of the content in the slips were a prerequisite of analysis and evaluation (Bloom & Krathwohl, 1956). In terms of cognitive demand, it is a task low in cognitive complexity, requiring comprehension of the digital slips provided on the tabletop and with no intentional for reasoning embedded in the design (+single task; +Here-and Now; −no reasoning)(Robinson, 2005). Both Groups A and B enlarged and read slips individually with limited interaction with each other (Fig. 7), and quickly moved to grouping task. In contrast, Group C decided to read together. While reading, they were trying to evaluate the usefulness of each of the statements. Episode 1: The case of useful or useless information.

Participant	Turns		Reasoning Skills
1 Wen:	Let's read together, which is the first one?		Propose a plan
2 Zhi:	*Bus service in this area are often unreliable*, yeah, that's maybe the reason.		(Read) Evaluate
		Just put the useful information there, and the useless there, okay?	
3 Wen & Lin	Okay		
4 Lin		I think this one is useless	Evaluate
5 Zhi:	Not useful?		Query Lin's evaluation
6 Lin:	Yeah		Confirm
7 Zhi:	And *local council encourages new businesses to locate on the edge of town*		Read to check
8 Wen:	*for the development.*		Join Zhi with reading
9 Lin:	Maybe reasonable.		Adopt alternative view
10 Zhi:	Yeah.		

11 Lin:		So put here. What about this?	Invite propositions
12 Zhi:		It's one of the reasons	Evaluate
13 Lin:	Yeah ((Drags slip))		Agree
14 Zhi:	*Why does Gail weekly shopping trip take.*		Revisit the task Q
15 Wen:	*40 min longer? Car ownership has increased. . .*		(Read)
16 Lin:	I think this is reasonable for that longer time.		Conclude

(Numbers refer to participant turn lines from the transcripts).

As illustrated in Episode 1, students were discussing the usefulness of the statements (Turns 2, 4 and 16) one by one. Interactions show that enlargeable slips encouraged joint reading and facilitated thinking. The use of deictic expressions 'this, that, here, there' indicated a shared context of presented information on the tabletop, which brings the events *Here-and-Now* (Robinson, 2005) for referencing. The referencing in return eases mental workload, allowing students' more space to concentrate on evaluations.

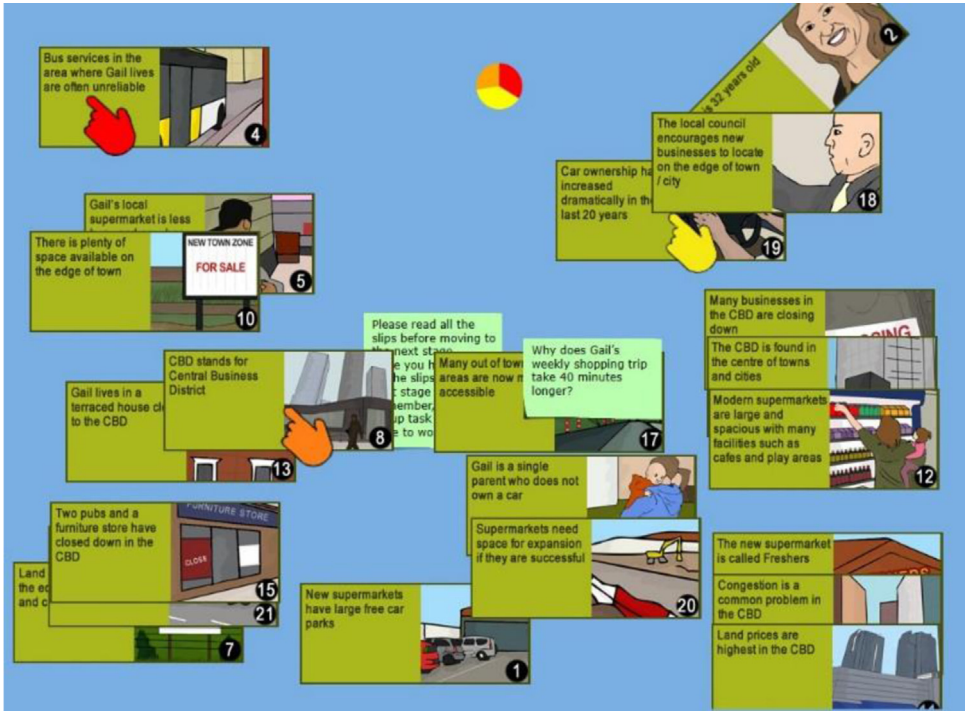
5.2.2. Analytical skills

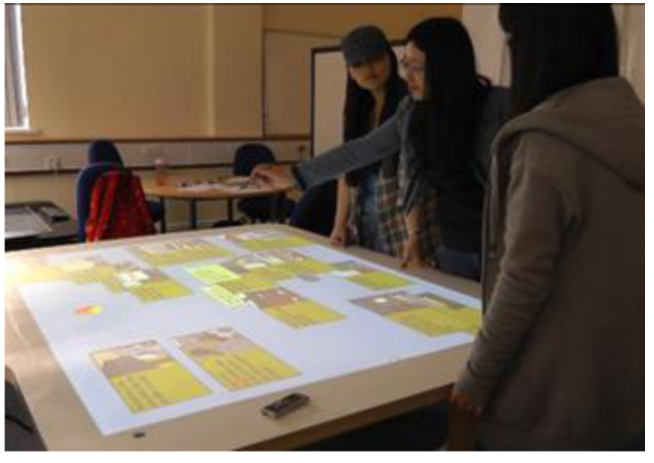
The ability to identify relations is one of the basic analytical skills for critical thinking. At the Grouping stage, students were asked to create at least three groups. To group slips, students not only needed to understand the content in a slip, but also were able to compare and contrast, seeking similarities and differences between and among the slips. It is higher in cognitive complexity than comprehension, as it involved more than one steps to complete the task (+few elements; −single task; +reasoning) (Robinson, 2005). Many examples in the data suggest that some of the relations are easy to recognise, while others might not be that obvious. Episode 2 is an example where visibility of student thinking is mediated in the environment through collaborative coupling and the affordance of off-table reasoning.

Video data shows that students in Episode 2 were very quick and assertive in deciding that unreliable bus services is one of contributing factors to 'longer time', while the statements of CBD, local council and Gail are useless information (1–4) as evidenced in the log at Turn 8. The slips displayed on the tabletop drew students into active engagement in examining, discussing and identifying relations between slips through collaborative coupling (6–12). Parallel, as well as collaborative, thinking was observed, moving between individual thinking, thinking together, and mediating each other's thinking. The use of discourse markers of 'Oh, I see' (9) suggest a lightbulb moment when listening to Wen's reasoning, Zhi suddenly realises that some of the statements they put in the useless category could be related to the key information in the useful category. As a result, they retrieved the statement of local council from the useless category and put it in the useful category. Collaboratively they established that 'a little bit far supermarket' was the causal reason for 'longer time'. In terms of reasoning skills, we see intentional use of logic subordinators 'so, because' to mark cause and effect. Overall use of the L2 was economical, as students all knew which slips the speaker was referring to even if she did not spell the content out in full. Wen, on the other hand, used provided information creatively in conceptualising her reasoning.

Episode 2: The case of the related information.

Participant Turns			Reasoning skills
1 Zhi:	*CBD stands for*. . . this is. . .		Invite propositions
2 Lin:	No.		Evaluate
3 Zhi:	Not useful (Drag).		Agree
4 Lin:	This is not, right? Not related.		Evaluate
5 All:	(Read slips)		
6 Lin:	What about this?		Invite propositions
7 Wen:	It's really about, so he should drive outside the city to get more from the supermarket because the local one is having less choices of goods.		Reason with 'so'
8 Lin:		Oh. . .yes, this one is about	Invite propositions



9 Zhi:		Oh, I see, maybe some of the slides are related because...	A lightbulb moment Reason with 'because'
10 Lin:	A little bit far supermarket.		Reason
11 Zhi:	Yeah.		
12 Lin:	So it takes a little bit longer time.		Conclude with 'So'
13 Zhi:	Yeah, maybe not that direct, that's a direct answer.		Agree
14 Lin:	Yeah.		

5.2.3. Causal reasoning

What is obvious from the examples in Episode 1 and 2 is that relations can be analysed from more than one perspectives. Arrow sticky tapes provide an external device to mediate students' casual reasoning (Vygotsky, 1978). At the Sequencing stage, students were asked to identify key slips that could give them a sequence to answer the question. This task is higher in cognitive complexity than comprehension and grouping, as students are required to find out causal relations within a pair or between pairs of statements before they can put pairs of causal effect in an inferencing and logic order. Sequencing demands multiple applications of the cognitive processes involved in the identification and reasoning of causal relations, and the additional '+' is used to illustrate the degree of the complexity (++ few elements; ++ reasoning) (Robinson, 2005). Group interaction shows that students found it hard to decide causal relations. Physically using arrow sticky tapes to connect selected statements forced students to decide which was 'cause' and which was 'effect', which in turn externalised students' interpretations of causal relations on the tabletop, making it visible and accessible for evaluation, reflections and modifications either by themselves or by peers. Episode 3 exemplifies how students identified a chain of causal relations with the help of arrow sticky tapes.

Episode 3: The case of causal relationship.

Participant Turns		Reasoning Skills
1 Tan:	I think, maybe, the supermarket, em, was, em was transferred to another, to the edge of the city, so should take more time to go to that supermarket.	Identify cause and effect
2 Yang:	Yeah, but why the supermarket moves to other, so because we have.	Identify effect
3 Tan	Because the price of the land in the city.	Identify cause
4 Yang:	Yeah, so.	
5 Tan:	So, let's link the information.	
6 Tan & Yang	(Connect slips)	

In Episode 3, students identified two pairs of causal relations. Yang's questioning of why the supermarket moved to the edge of town led them to see the causal relations between the two pairs. Supermarket moving out of the city is the cause for taking longer time in the first pair, but is also the effect of the high price of land in the city in the second pair. They linked the statements to confirm their reasoning.

5.2.4. Logical reasoning

Episodes 1–3 show increased management of complexity in actions ranging from comprehension, grouping to analysing causal relations. The biggest challenge for the students is to sequence identified pairs of cause and effect in a logical order, though ample examples in the sessions showed that students were able to figure out causal relations among two or three slips. Sequencing represents the highest cognitive demand task in the DM (++few elements, ++reasoning, −single task, +prior knowledge) (Robinson, 2005). It requires multi-tasks of identifying causal relations within and between pairs, reasoning and selecting the most relevant reasons to justify the causal relations to 'the longer time', retrieving previously identified causal pairs, or seeking new relations. An analysis of groups' answers to 'Why does Gail's weekly shopping take 40 min longer?' revealed that all the groups reported key factors. However, it is their ability to see overall links between previously identified individual causal links and ability to put them logically in an inferencing chain that has differentiated their answers. This is shown in our comparison of the final group answers (Figs. 10, 11 and 12 respectively).

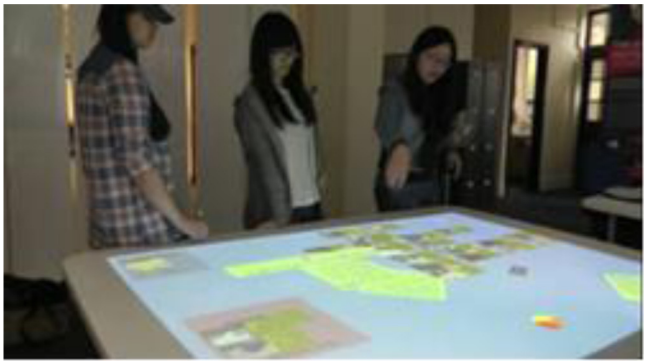
Episode 4: Group A's answer.

Participant Turns		Reasoning Skills
1 Facilitator:	Well, this go back to your recordings on the screen. Would you like to give me some summaries about how you found the answer, the answer of why Gail's weekly shopping take minutes longer.	
2 Li:	Er. because of the bus services	Reason 1
3 Wang & Zha:	It's not reliable	Complete Li's reason 1
4 Facilitator:	Yeah, and...	
5 Zha:	And the supermarket is built in the rural area, **so** it takes long time to get to there.	Reason 2 + conclusion with 'so'
6. Facilitator:	There are also reasons for the supermarket to move, so what's the reasons?	
7 Li:	**(Be) Cause** the land prices in the CBD is very high (Reason 3), and there are congestion problems (Reason 4), and I think government encourages the business to move from the city centre to the edge of the town (Reason 5)	Reason 3 Reason 4 Reason 5
8 Wang:	More space for parking	Reason 6
9 Li:	And the land prices is cheaper	Reason 7
10 Zha:	And the facilities are much more in the area.	Reason 8

Episode 4 shows that Group A's answer consists of a list of reasons. Students reported key factors, however most of these factors were loosely connected with no indication of causal relations apart from one (5). A close examination of listed reasons reveals that 6–8 are all about the new supermarket, while 3–5 are about CBD. Although using their own words in constructing their answers, they failed to state the logical relations between these cited reasons explicitly. Limited use of reasoning words was also noted.

In comparison to the answer given by Group A, Group C's answer not only includes most of the key information but is also organised by causal relations.

Episode 5: Group C's answer

Participant Turn		Reasoning Skills
1 Facilitator:	So, can give me a summary to answer the question, yes?	
2 Lin:	Er, I will answer this one,	
	er, because Gail doesn't own his own car, her own car, and *there*, maybe she need more time to take the public transportation (Reason 1), and the bus services, and also about there are more and more cars in the city centre, **so** the congestion is a serious problem (Reason 2), so these **result in** the bus service in the area where Gail is not very good (Reason 3), **so** she need more time on the road, er, no no no, on her way to the supermarket, so that's why take 40 min longer okay?	Reason 1 + conclusion Reason 2 + conclusion with 'so' Reason 3 + main conclusion
3 Facilitator:	You all agree with that? Do you want to add something?	
4 Zhi:	Yeah, I think a lot of reason that leads to the only choice of Gail that she has to go to the supermarket, er, far away from CBD,	Reason 4 + conclusion
	 Just like all the reasons lead to here	
	because of the reasons why the supermarket need to move out of to CBD, and then she has to, she has less choices in the local supermarket, so she needs to go to the supermarket further from her home, and that's the reason.	

Episode 5 shows two subsets of the argument. Lin concentrated on Gail, believing that not having a car was the reason that caused Gail 40 min longer for the weekly shopping trip. However, she failed to justify why Gail had to go to the supermarket far from her home in the first place. We see after teacher's facilitation (3), Zhi added reasons that lead Gail to do her shopping at the big supermarket out of town. She pointed to the piles of slips indicated by the discourse marker 'Here' to support her reasoning, though did not make any explicit reference to the logical relations between the two subsets of reasoning. In fact they missed cheap price of the land, a main reason for moving the supermarket out of city centre. The ability to synthesise logical relations between all the slips allowed Group B to outperform Group C.

Episode 6: Group B's answer.

Participant Turn		Reasoning Skills
1 Tan:	Ah, I have new, I have a new idea em, because before the supermarket moved to the new place, Gail could buy things near to her house.	Reason 1 + conclusion
2 Yang:	Yes	
3 Tan:	However, when it transfers to a new place, she should, em, take more, em.	Reason 2 + conclusion
4Yang:	Yes, Yes, all of the reasons cause her took long time.	Find supporting evidence
5 Liu:	I know, I know.	
6 Yang:	What do you think so?	Invite confirmation
7 Tan:	 Em, let me think.	Think
8Yang:	Yeah.	
9 Tan:	This is why she could use less time, em, before	Intermediate conclusion (IC)
10 Yang:	Yeah, yeah.	
11 Tan:	However, em, I found some reasons about the, but she doesn't have a car.	Reason 3

12 Yang:	Yeah.		Acknowledge
13 Tan:	So she have to take public transportation.		Conclusion 3
14 Yang:	Yeah.		Acknowledge
15 Tan:		But there are some reasons about the transport	Find supporting evidence
		*Here.*	Fetch evidence
17 Tan:	Er, so.		
18 Yang:	Bus service in the area Gail lives are over unreliable.		Reason 4
19 Tan:	Yeah, maybe, this is one of the reasons to the main question, I think.		Main conclusion
20 Liu:	Single parent		Reason 5
21 Yang:	Doesn't have a car is also. . . No, no, I don't think this. This is important because she doesn't have a car is also important why chooses beside. . .		Examine causes and relations
22 Liu	Single parent right?		Repeat reason 5
23 Tan:	Because she does not own a car.		Repeat reason 3
24 Yang:	Em, I understand. How about like this, because, let's say, because Gail is a single mother, she does not own a car, that's why she chooses the supermarket beside her home, right? But because of these reasons, new supermarket moves to other city, and then, she needs to take bus, took bus to the supermarket, and a lot of congestions also, as a lot of congestions, and, that's why it took longer time. Am I right?		A Penny drop moment Construct an argument
25 Liu:	Are you making a conclusion?		
26 Tan:	I agree.		
27 Yang:	Can you repeat what I said?		
28 Tan:	It's Gail is a single mother, and she does not have a car, so she decided to go to the supermarket that is close to her home, however, there are some policy and advantages for the supermarket to transfer to the new place, so she has. And also, this is another question, em, another reason that she find that there is, em, the supermarket is less busy, and have less choices of goods and products, so she decided to go to the new supermarket. However, the transportation there is really, but, yeah, maybe, yes the transportation is serious, so it takes longer time for her to go to supermarket.		

Episode 7 illustrates processes of the construction of reasoning, a high level of cognitive complexity task engaged by students in Group B. They need to consider many different facts and factors; on top of reasoning, they had little planning time in constructing their answer (Robinson, 2005). Before moving to examine factors that could have caused 'longer time', as shown in Fig. 12, they investigated reasons that Gail needed less time for her weekly shopping before the supermarket moved to the edge of the city, which led them arrive at an intermediate conclusion (9) (Van den Brink-Budgen, 2000), There are evidences that the tabletop assisted and mediated students' reasoning, logical thinking, and argument construction by providing an overview of their thinking, access to retrieve information from multiple categories (15 and 16), and language input to articulate their reasoning in L2. Students were observed working 'off table', examining logical relations within and between topics of the new or old supermarket, between the car ownership and traffic problems, between Gail and the new and old supermarket when suddenly a penny drop moment occurred. Suddenly, all the pieces of information fell into its

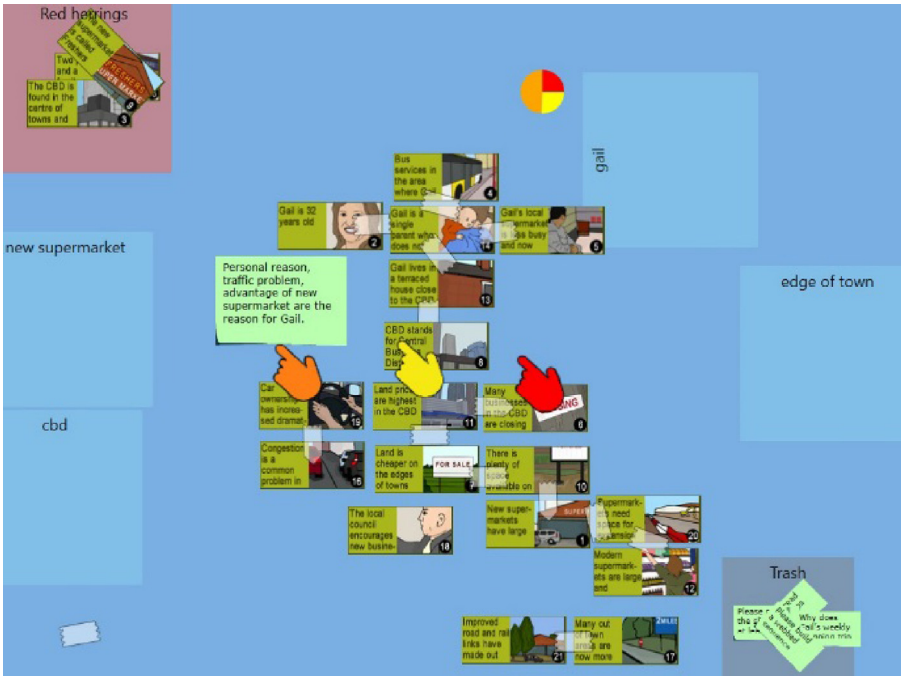


Fig. 10. Group A's answer from the interaction log.

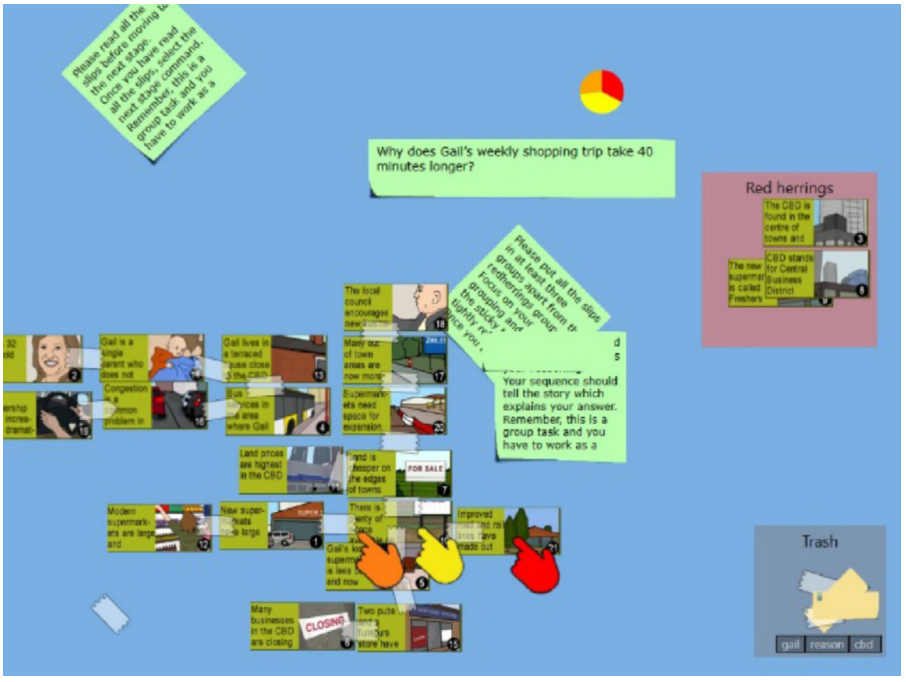


Fig. 11. Group C's answer from the interaction log.

place and Yang saw the links of all the causal pairs. She verbalised her line of reasoning in one breath (24). She was so engaged in constructing her reasoning without realising it till the end. Production of reasoning seems to have exhausted all her cognitive resources, she couldn't remember what she had improvised and asked her peers to repeat what she had just said (27). It is noted in Yang's reasoning that she used cognitive resources selectively. Yang did not specify individual reasons why the new supermarket moved to the edge of the city, referring them as 'because of these reasons' (24) so that she could concentrate on her argument. In the repeated version, however, we see all the gaps were filled, and relevant connectors were added to make the argument self-explanatory.

Fig. 12. Group B's answer from the interaction log.

5.3. Technological design features and reasoning skills

Here we discuss the findings in terms of the affordances of the Digital Mysteries and tabletop more broadly. The physical form factor of the tabletop played a positive role in providing a natural, face-to-face style of communication (Higgins et al., 2012; Kharrufa & Olivier, 2010). The large horizontal surface provided a good common focal point for discussing content. This was made evident by the use of words 'here', 'there', 'all 'these' about reasons why' and the rich use of deictic gestures (i.e. pointing) when referring to content.

Specific design features of the Digital Mysteries application played an important role in encouraging and driving discussions to promote the use of higher level thinking skills, particularly the grouping design feature and the normal and arrow shaped sticky tapes.

The use of a structured activity with distinct grouping and sequencing stages aims at encouraging students to examine the information from two different perspectives first in terms of organizing information, then moving to a higher level of thinking focusing on causal relations. The interaction analysis showed how, in moving from grouping to sequencing stage, students dragged slips out of the categories they generated at the grouping stage and completely reorganised them to align with a new perspective. More importantly, having a dedicated sequencing stage with arrow shaped sticky tapes specifically designed to indicate causal relations, forced students to think carefully about the reasons or consequences. The transcripts reveal a number of examples of how selecting the arrow shaped sticky tape led student to re-examine their previous interpretations and decisions.

5.4. Limitations and future work

Our work has shown how applications such as Digital Mysteries on multitouch tabletops allow tasks and interactions to be structured within the context of second language learning. A limitation of this paper, due to space and scope, is the omission of any specific focus on opportunities for teacher observation and assessment as part of the value of tabletops for making thinking explicit. This is an area which is central to the affordances of CSCLE's as digital tabletop applications like DMs allow learner activity to be logged for formative and summative assessment. In other work, we have explored the value of other applications such as Co-located Collaborative Writing (CCW) which matured from a scaffolding mechanism for planning, to a tool for implementing planning (Heslop et al., 2015). We intend to follow up the study reported in the paper with a specific focus on teacher as well as peer assessment.

6. Conclusions and implications

In this paper we have demonstrated that critical thinking and reasoning in the L2 is of high level of cognitive complexity, and the completion of tasks of high level cognitive complexity in a CSCLE clearly prompts students to articulate their thinking

and importantly, make it visible. Interactional evidence confirms that students used analytical, evaluative and reasoning skills and the digital tabletop assisted students' process of thinking critically and self-regulating their thinking behaviours. While they constantly cross-referenced each other for propositions or ideas during the process of reasoning, it is the effort they made in questioning their own position and seeking or offering justifications of others' views (Jewell, 1996) that deepened their exploration of various relations. These actions have the potential to lead to improved outcomes. Pedagogically, this implies a need to nurture students' critical thinking dispositions through making thinking visible in order to develop their critical thinking skills (Zin & Wong, 2014).

In terms of the management of cognitive complexity in critical thinking tasks in L2, this study shows how a task can be structured to ascertain a progression in the demand of cognitive resources (Robinson, 2005). The findings and discussions concerning the affordances of the environment indicate that separating comprehension and grouping tasks of the statements eased the mental workload. Likewise, the grouping sub-task let students rehearse their interpretations of relations among statements, so when the time came to sequence them, students had already worked with the content twice. Therefore, they did not enter the task cold. Dealing with one thing at a time not only reduces cognitive demand (de Bono, 2000; Robinson, 2005), but also improves the efficiency of using cognitive resources. For that reason, we would argue that with careful sequencing, it is possible to increase the cognitive complexity of learning tasks with reduced mental workload in information processing.

Our study also shows how technology with a well-developed instructional design used within a CSCLE can facilitate task completion which is high in cognitive complexity. Using digital cognitive tools such as sticky tapes can push students to think more and be more logical. The tabletop facilitated multimodal interactions in CSCLE and enhanced thinking-in-action in this face-to-face communication context. The tangible mapping mirrors students' thinking-in-action, and made it easy for them to share, review, and reflect on their thoughts. Equally, the content on display assisted thinking-in-action and verbalisation of thoughts. The natural and creative use of language in the interaction suggests that the content on display decreases the burden on L2 learners' working memory by reducing the demand of searching for words to transfer their thoughts into speech. This supports Skehan's (2015) claim that managing and easing cognitive resources makes limited working memory work better in L2 performance in high complexity tasks.

Educational experience is a significant predictor of the development of student cognitive complexity (Simmonsa, 2014). This study supports arguments that students can be trained to think critically (Sanavi & Tarighat, 2014) in CSCLEs, which allow for face to face communication as it specifically encourages talk and the promotion of thinking skills. Applications such as Digital Mysteries can play a significant role in this form of training. Given the emphasis that critical and creative thinking places on the implicit and explicit second language education curriculum, language educators may benefit from developing a broader understanding of cognitive complexity of learning tasks specifically in CSCLEs in order to help students make the transitions associated with increasing cognitive complexity (DeLoach & Greenlaw, 2007). Appropriate and relevant mediation is needed to promote student critical thinking, including learning environments which encourage and support making critical thinking visible, teaching vocabulary of critical thinking to enable students to articulate their thinking, and instructions of using specific terminology to make targeted critical thinking skills explicit (Kabilan, 2000). To this end, we believe that the integration of the teaching of critical thinking skills and more specifically reasoning skills into the L2 classroom can be supported through new technologies. Rather than something that is done to students, the use of technology should be viewed as part of a broader ecology of the L2 classroom where the affordances of the environment as a whole, including peers, teacher and technology come together.

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